Multi-Particle Measurement in Polarized Proton-Proton Collisions at PHENIX

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Contents

Introduction

- Nucleon spin problem (EMC 1988), gluon polarization in the proton Δg

$$\frac{1}{2}_{\text{proton}} = \frac{1}{2}\sum_q \Delta q + \Delta g + L_{q,g}$$

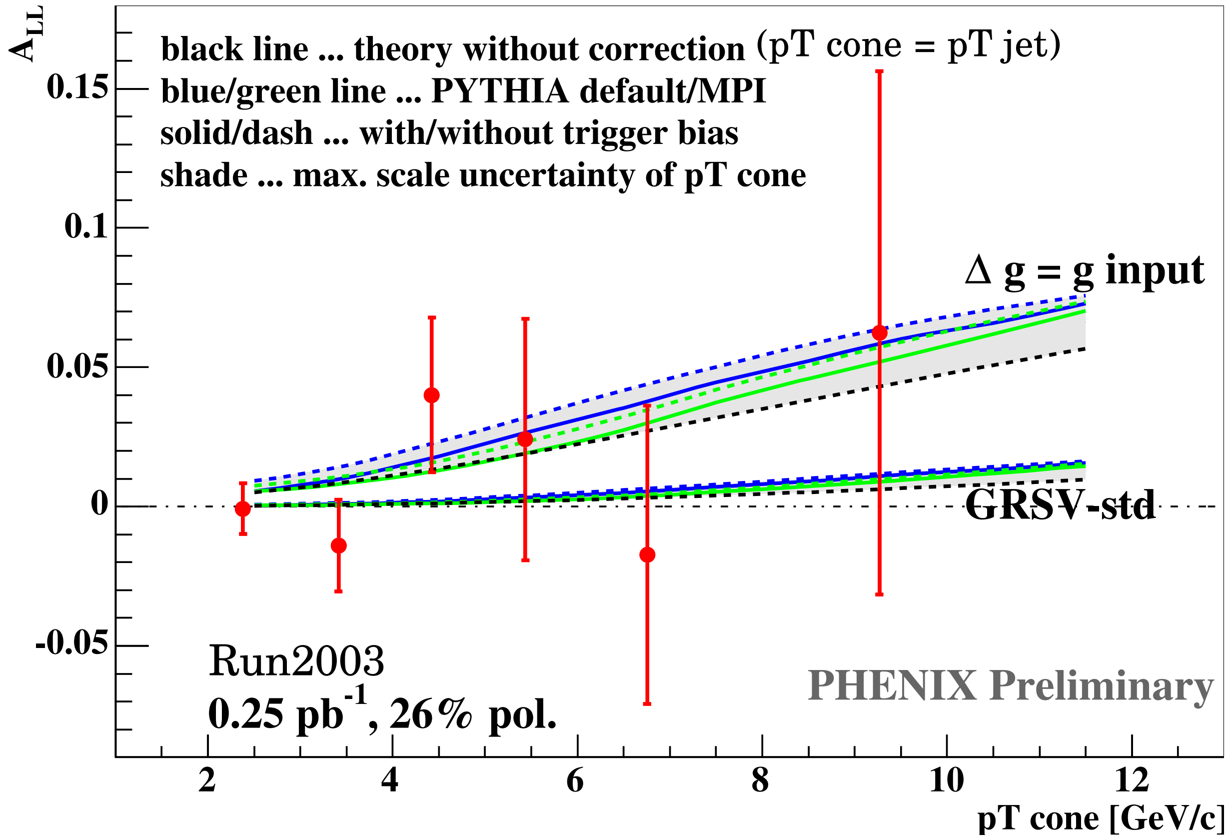
  - reactions accessible to Δg ... jet, inclusive π^0, direct photon, etc.
- Measurement of multi-particle as a part of jet with PHENIX Central Arm ($\Delta\phi = 90^{\circ} \times 2$, $|\eta| < 0.35$) is sensitive to Δg as shown in next page
- Double helicity asymmetry (A_{LL}) in jet production

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad , \qquad R \equiv \frac{L_{++}}{L_{+-}}$$

  - A_{LL} has information on Δg
    - g+g and q+g reactions are dominant in mid-p_T jet production
    - for $gg \to gg$ reaction, $A_{LL}^{gg\to gg} = \int dx_1 dx_2 \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{gg\to gg}$
  - A_{LL} in multi-particle measurement is a modified A_{LL} of jet production

Introduction

- Double helicity asymmetry A_{LL} in multi-particle measurement

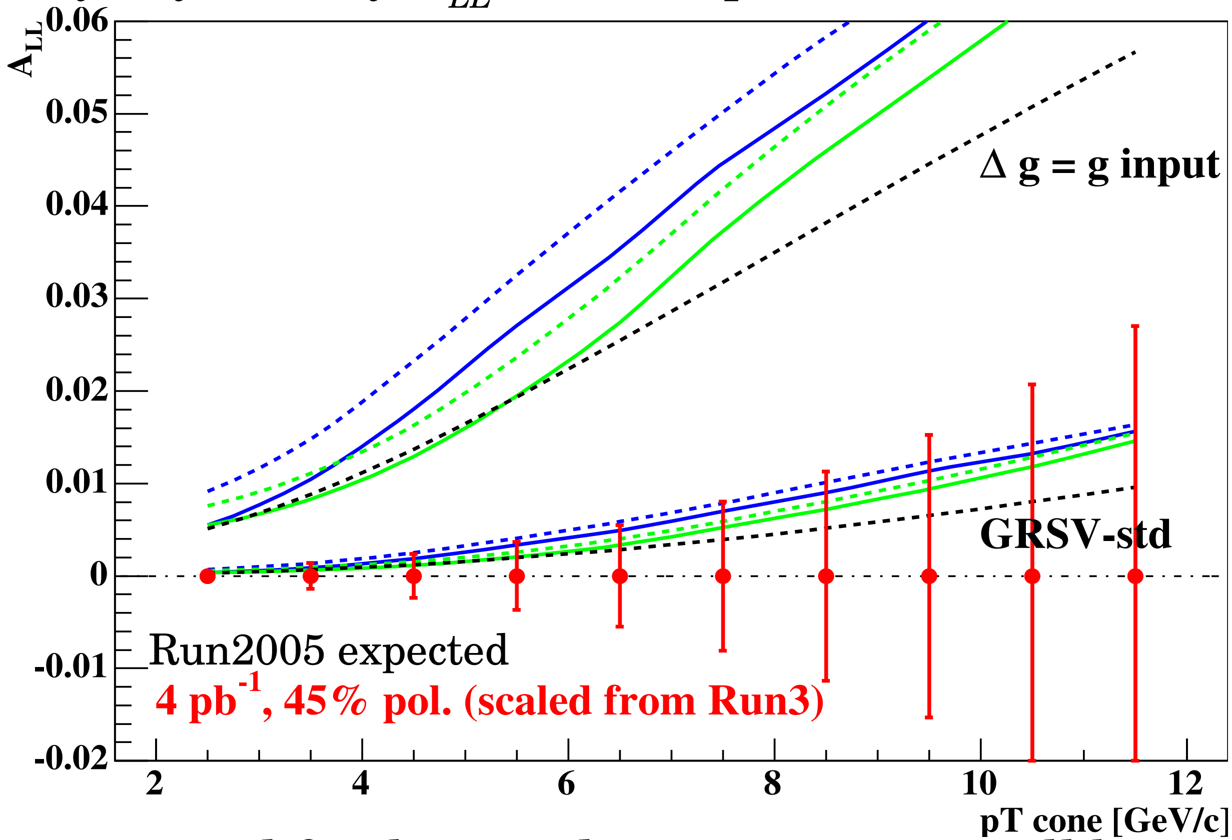


$$p_T^{\text{cone}} \equiv \sum_{i \text{ in cone}} p_{Ti}$$

- PYTHIA ver. 6.220 default setting and MPI setting were used
  - MPI (Multi-Parton Interaction) ... tuned with CDF Run2 data by Rick Field (R. Field Tune A setting)
  - PYTHIA MPI generates event structure (multiplicity, thrust in acceptance, and pT density in δφ) better than default

Introduction

- Double helicity asymmetry A_{LL} in multi-particle measurement

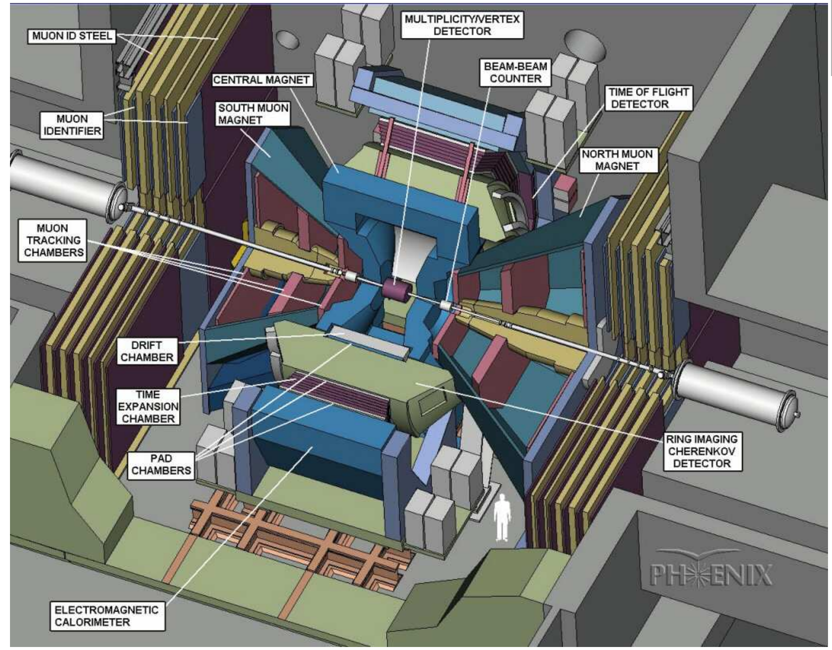


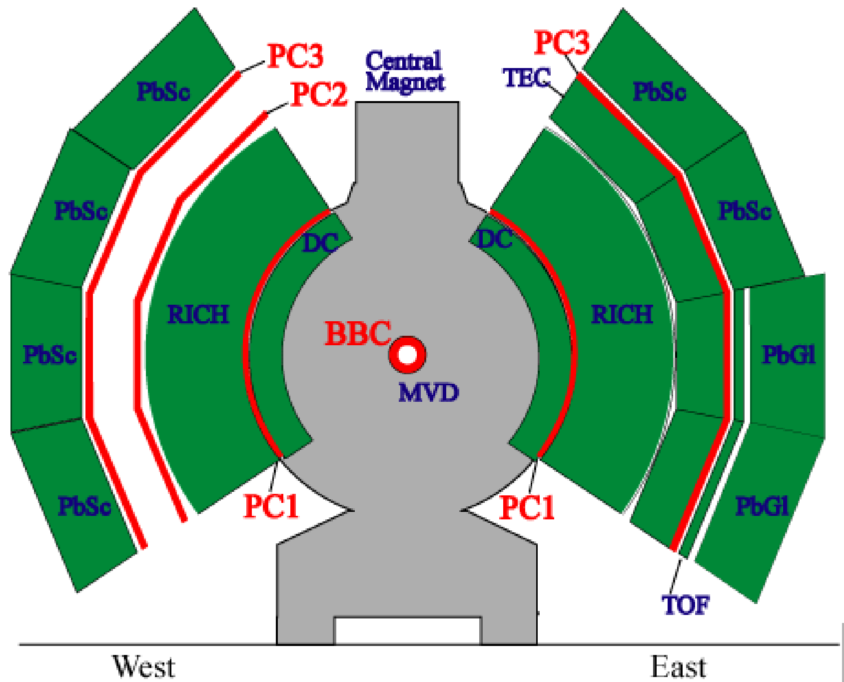
$$p_T^{\text{cone}} \equiv \sum_{i \text{ in cone}} p_{Ti}$$

  - Run2005 stat. and further study on sys. errors will bring conclusive result
- Inclusive jet production cross section by multi-particle measurement
  - it will show how well we are measuring jet and its p_T
- Analysis method and current status on jet cross section measurement is presented in this talk

Experimental Setup – PHENIX@RHIC

- Longitudinally polarized proton-proton collision at $\sqrt{s}$ = 200 GeV at RHIC
- PHENIX Central Arms: $\Delta\phi = 90^{o} \times 2$, $|\eta| < 0.35$
- Event selection
  - p_T(photon) > 2 GeV/c (offline trigger)
- Particle selection
  - photon: detected with EMCal
    - p_T > 0.4 GeV/c
    - shower shape cut
    - veto of charged particle
  - charged particle: detected with Drift Chamber & Pad Chamber 1
    - 0.4 < p_T < 4.0 GeV/c
    - track quality cut





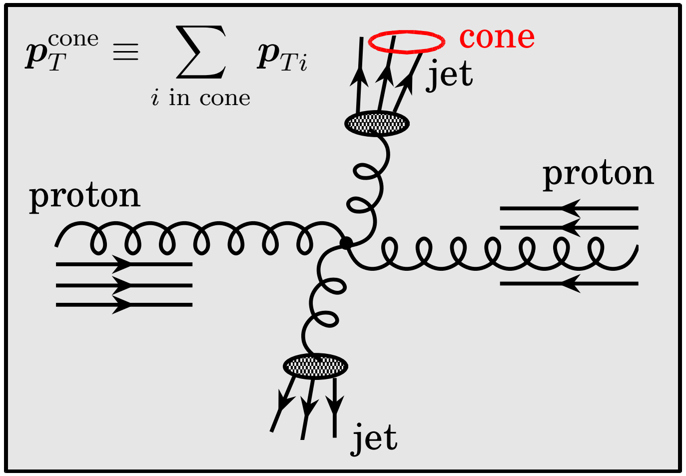
Outline (Analysis Method)

- Analysis outline
  - N^{cone} as a func. of p_T^{cone}
    (high-p_T photon trigger,
    cone method for particle clustering)

    p_T^{cone}-p_T^{jet} relation with PYTHIA+GEANT
  - N^{jet} as a func. of p_T^{jet}

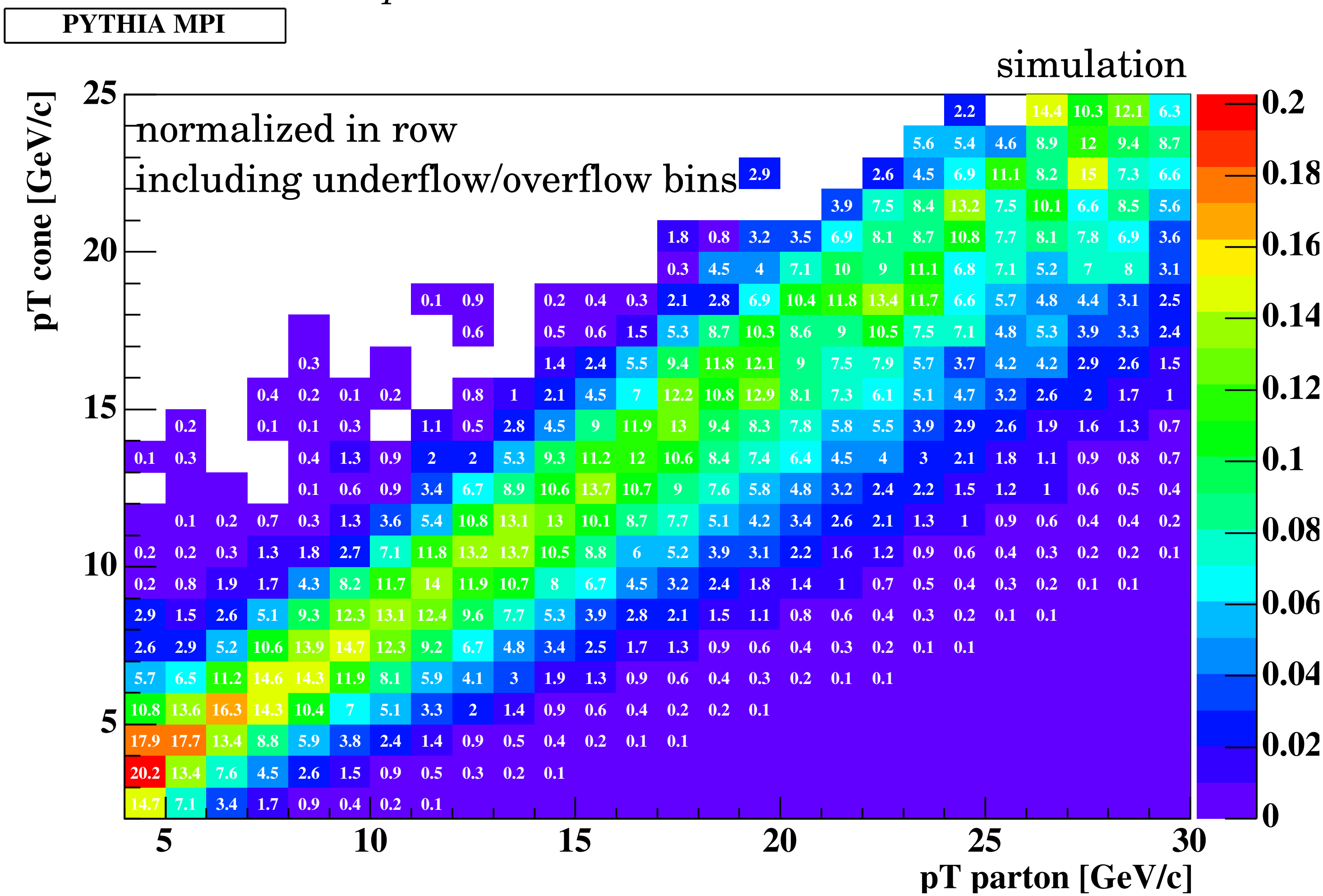
    high-p_T photon efficiency and acceptance corrections with PYTHIA
  - $N^{\mathrm{jet}}_{\mathrm{corr}}$ as a func. of p_T^{jet}

    global factors (luminosity, BBC high-p_T event eff., etc.)
  - σ^{jet} as a func. of p_T^{jet}



Relation btw. p_T^{cone} and p_T^{jet} (Analysis Method)

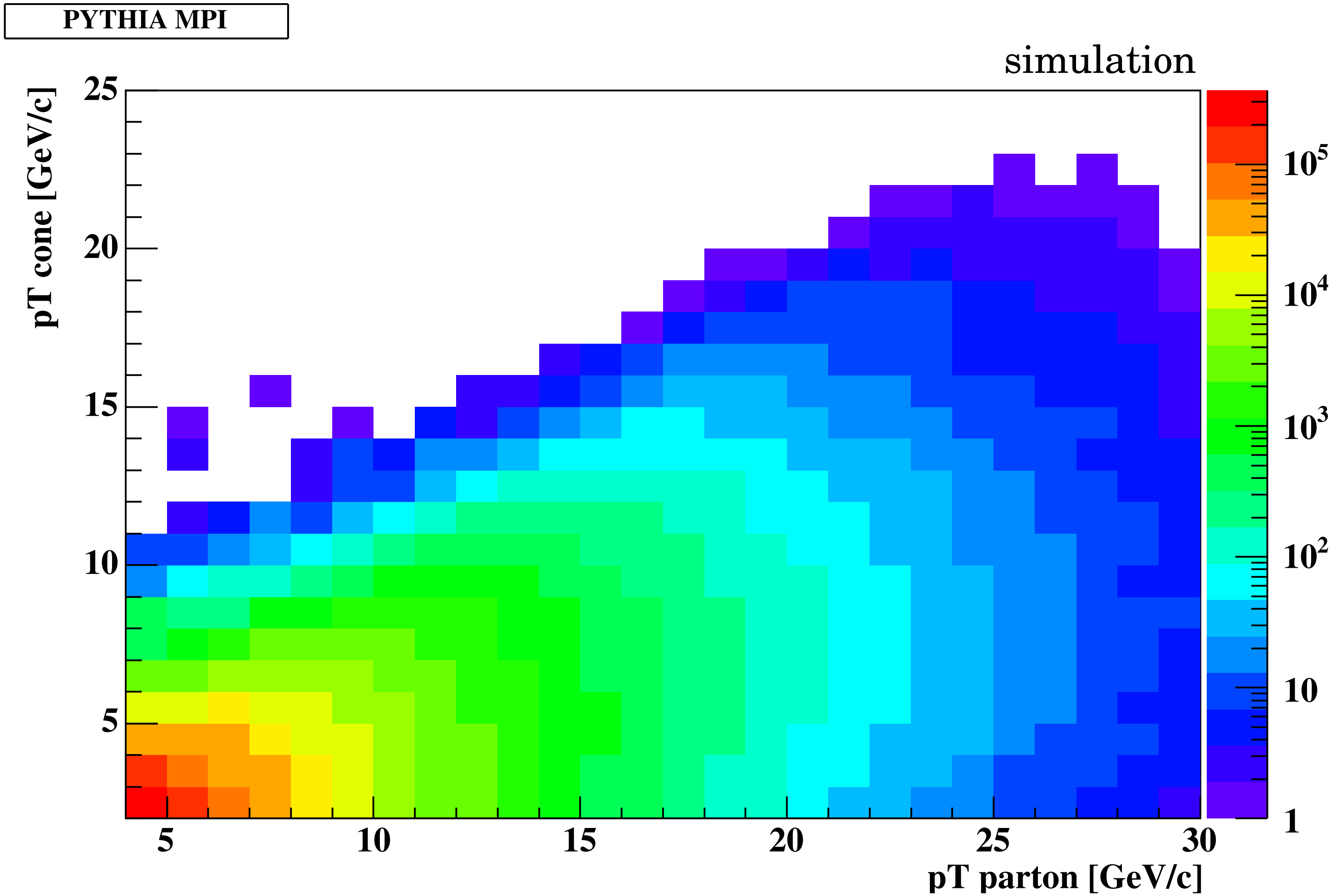
- Comparison in each p_T^{cone} bin (evaluated with PYTHIA+GEANT)



- most events in each p_T^{cone} bin have $p_T^{jet} \sim p_T^{cone}$ / 0.7
  - good for A_{LL} measurement

Relation btw. p_T^{cone} and p_T^{jet} (Analysis Method)

- Absolute comparison in p_T^{cone}-p_T^{jet} space (evaluated with PYTHIA+GEANT)



  - events in many p_T^{cone} bins contribute to one p_T^{jet} bin
    - a jet slightly out of acceptance can make smaller p_T^{cone}
    - difficulty in cross section meas. (unfolding method is under study)

Corrections to N^{jet} (Analysis Method)

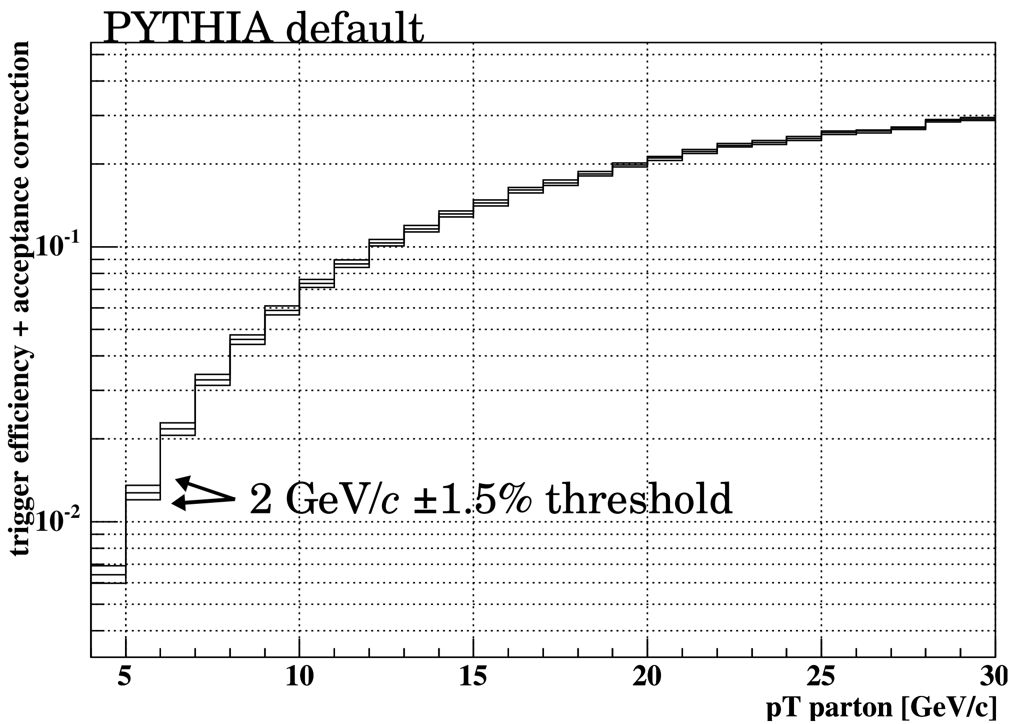
- Corrections for high-pT photon efficiency and acceptance
  - correction factor was evaluated with PYTHIA (without PISA, numerical cut for p_T, η and ϕ)
  - high-p_T photon efficiency
    - only jets including high-p_T (>2.0 GeV/c) photon were measured
    - the probability that jets includes high-p_T photon were evaluated
  - acceptance
    - the acceptance in the experiment is for trigger photons, not for jets
    - the correction factor from trigger ph. acceptance to jet acceptance were evaluated

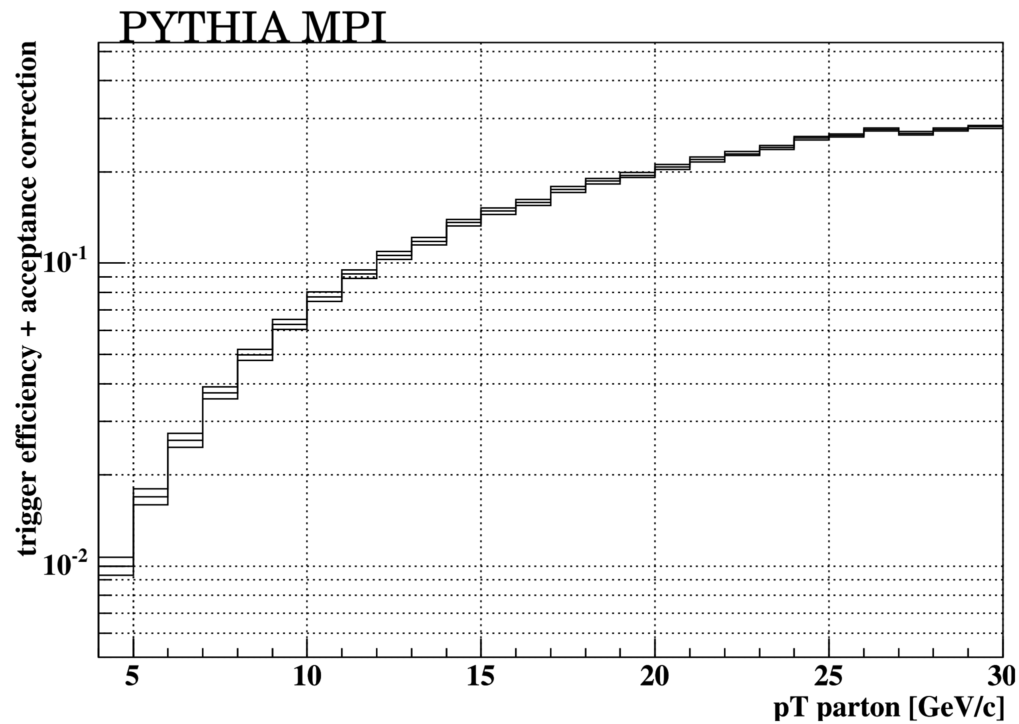
$$\epsilon \equiv \frac{p_T^{\text{ph}} > 2.0\ \text{GeV}/c\ \&\&\ \left|\eta^{\text{ph}}\right| < 0.35\ \&\&\ \Delta\phi = 90^o \times 2}{\left|\eta^{\text{jet}}\right| < 0.35}$$

Corrections to $N^{\rm jet}$ (Analysis Method)

- Corrections for high-pT photon efficiency and acceptance

$$\epsilon \equiv \frac{p_T^{\rm ph} > 2.0\ {\rm GeV}/c\ \&\&\ |\eta^{\rm ph}| < 0.35\ \&\&\ \Delta\phi = 90^o \times 2}{|\eta^{\rm jet}| < 0.35}$$

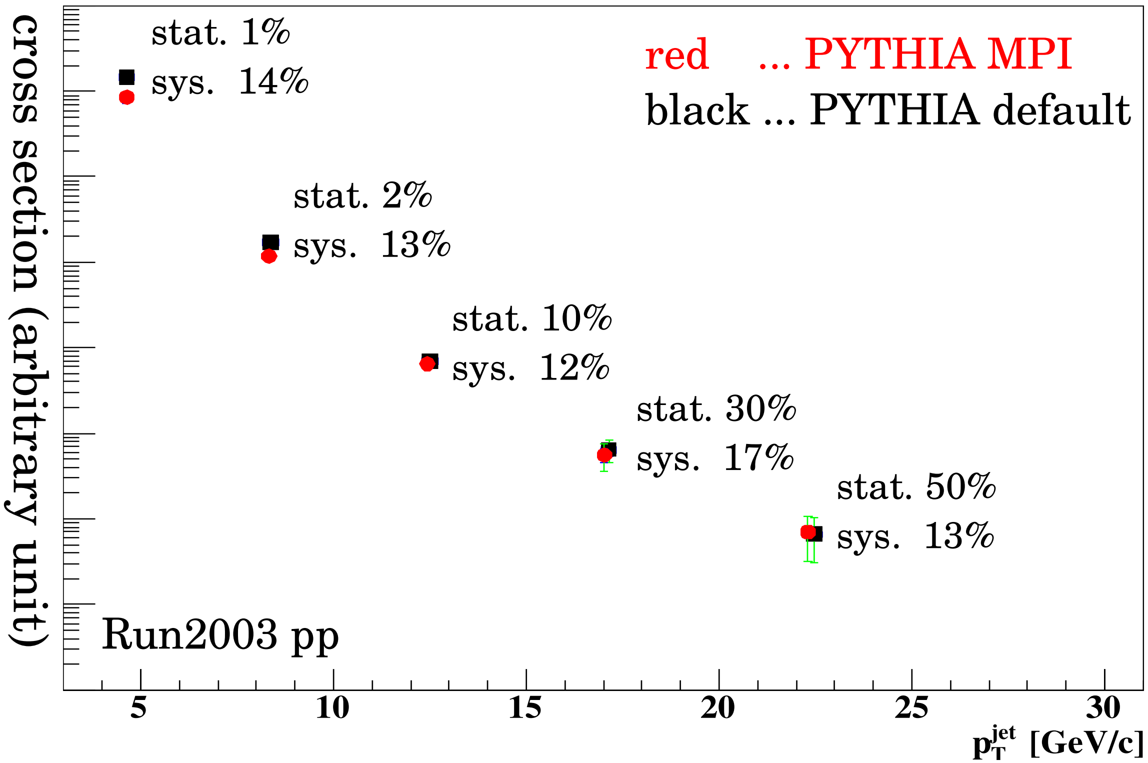




- 2 GeV/c ± 1.5% were used as threshold values to check the effect of the EMCal energy scale uncertainty ... 6~1% on cross section
- with PYTHIA MPI outputs, comparison of cross section with MinBias setting shows ~15% difference (under study)

Jet Cross Section (Analysis Method)

- Jet production cross section $$E\frac{d^3\sigma}{dp^3} = \frac{1}{L}\cdot\frac{1}{p_T^*}\cdot\frac{C_{\rm trig}}{f^{\rm BBC}}\cdot\frac{N^{\rm jet}_{\rm corr}}{\Delta p_T\Delta\eta\Delta\phi}$$



- systematic errors
  - assigned above; luminosity (BBC cross section) ... 10%, mom. scale of photon & charged particle ... 9% & 4%, etc.
  - under study; p_T scale in $p_T^{\rm cone}$ –> $p_T^{\rm jet}$ conversion, trigger efficiency

Conclusion

- The physics goal is to obtain the gluon polarization Δg in the proton. Measurement of multi-particle as a part of jet with PHENIX Central Arm ($\Delta\phi = 90^{o} \times 2$, $|\eta| < 0.35$) is sensitive to Δg.
- Inclusive jet production cross section by multi-particle measurement is being analyzed. It will show how well we are measuring jet and its p_T
- The relationship between p_T^{cone} and p_T^{jet} has been evaluated with PYTHIA+GEANT simulation. The fact that events in one p_T^{parton} bin contributes to many p_T^{cone} bins can cause large model dependence. Better unfolding method is under study.
- The major souces of systematic error in cross section measurement are luminosity (BBC cross section. 10%), mom. scale of photon & charged particle (9% & 4%), p_T scale in p_T^{cone} –> p_T^{jet} conversion (under study), and trigger efficiency (~15%, under study).
- Based on this achievement, A_{LL} in multi-particle measurement will be analyzed

Backup Slides...

Particle Clustering

- Particle clustering with cone
  - photons ($p_T > 0.4$ GeV/c) and charged particles ($0.4 < p_T < 4.0$ GeV/c) with offline high-p_T (> 2.0 GeV/c) photon trigger
  - make cones by using all particles as seed
    - cone radius $R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.3$
    - cone momentum = vector sum of mementa of particles in the cone
    - cone axis = direction of cone momentum (dir. of seed particle at first)
  - use cone with highest p_T^{cone} in events

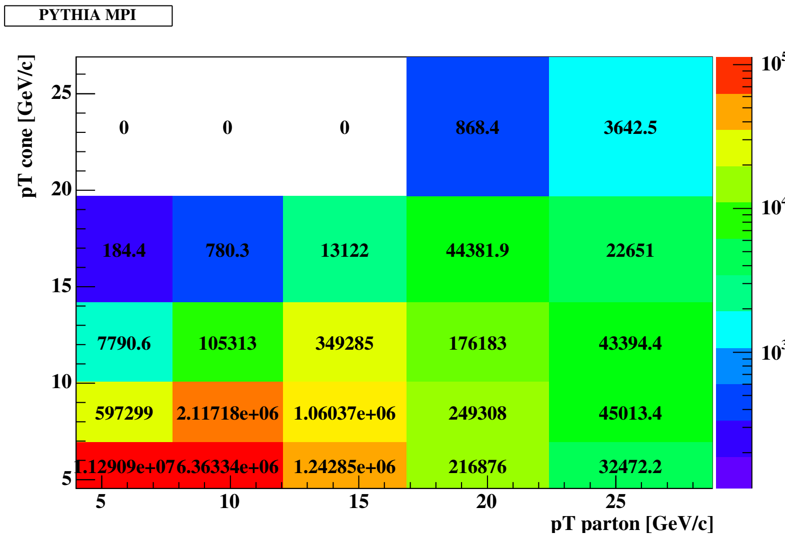
$$\boldsymbol{p}_T^{\text{cone}} \equiv \sum_{i \text{ in cone}} \boldsymbol{p}_{Ti}$$

Unfolding Method

- p_T^{cone}-p_T^{jet} relation
  - S_{ij} ... conversion matrix from p_T^{jet} to p_T^{cone} (by acceptance effect etc.)

$$S_{ij} \equiv \frac{\partial \sigma_i^C}{\partial \sigma_j^J} = \frac{n_{ij}}{n_j^J} \quad , \quad n_i^C = \sum_j n_{ij}$$

    - S_{ij} must be evaluated with simulation
    - n_{ij} ... event rate in (i, j) bin



- Folding/unfolding
  - N^C_i ... cone yield in i-th p_T^{cone} bin (measured)
  - N^J_j ... jet yield in j-th p_T^{jet} bin (true)
  - S_{ij}' ... square matrix with p_T^{cone} and p_T^{jet} ranges to be measured

$$N_i^C = S'_{ij} N_j^J \quad , \quad N_j^J = S'^{-1}_{ji} N_i^C$$

  - statistical covariance matrix

$$\nu(N_j^J, N_k^J) = \sum_{i1=1}^{n_{cone}} \sum_{i2=1}^{n_{cone}} \mathcal{D}(j, i_1) \mathcal{D}(k, i_2) \sigma_{N_{i1}^C} \sigma_{N_{i2}^C} \quad , \quad \mathcal{D}(j, i) \equiv \frac{\partial N_j^J}{\partial N_i^C} = S'^{-1}_{ji}$$